

**IN THE UNITED STATES PATENT AND TRADEMARK OFFICE**

**APPLICATION FOR LETTERS PATENT**

\* \* \* \* \*

**METHOD OF ADDRESSING MESSAGES AND  
COMMUNICATIONS SYSTEM**

\* \* \* \* \*

**INVENTOR**

**CLIFTON W. WOOD, JR.**

**ATTORNEY'S DOCKET NO. MI40-119**

**EL 169869615**

**EM 156304218**

00440 6629560

1 METHOD OF ADDRESSING MESSAGES AND COMMUNICATIONS  
2 SYSTEM

3 TECHNICAL FIELD

4 This invention relates to communications protocols and to digital data  
5 communications. Still more particularly, the invention relates to data  
6 communications protocols in mediums such as radio communication or the like.  
7 The invention also relates to radio frequency identification devices for inventory  
8 control, object monitoring, determining the existence, location or movement of  
9 objects, or for remote automated payment.

10  
11 BACKGROUND OF THE INVENTION

12 Communications protocols are used in various applications. For example,  
13 communications protocols can be used in electronic identification systems. As  
14 large numbers of objects are moved in inventory, product manufacturing, and  
15 merchandising operations, there is a continuous challenge to accurately monitor  
16 the location and flow of objects. Additionally, there is a continuing goal to  
17 interrogate the location of objects in an inexpensive and streamlined manner.  
18 One way of tracking objects is with an electronic identification system.

19 One presently available electronic identification system utilizes a magnetic  
20 coupling system. In some cases, an identification device may be provided with  
21 a unique identification code in order to distinguish between a number of  
22 different devices. Typically, the devices are entirely passive (have no power  
23 supply), which results in a small and portable package. However, such

1 identification systems are only capable of operation over a relatively short  
2 range, limited by the size of a magnetic field used to supply power to the  
3 devices and to communicate with the devices.

4 Another wireless electronic identification system utilizes a large, board  
5 level, active transponder device affixed to an object to be monitored which  
6 receives a signal from an interrogator. The device receives the signal, then  
7 generates and transmits a responsive signal. The interrogation signal and the  
8 responsive signal are typically radio-frequency (RF) signals produced by an RF  
9 transmitter circuit. Because active devices have their own power sources, and  
10 do not need to be in close proximity to an interrogator or reader to receive  
11 power via magnetic coupling. Therefore, active transponder devices tend to be  
12 more suitable for applications requiring tracking of a tagged device that may  
13 not be in close proximity to an interrogator. For example, active transponder  
14 devices tend to be more suitable for inventory control or tracking.

15 Electronic identification systems can also be used for remote payment.  
16 For example, when a radio frequency identification device passes an interrogator  
17 at a toll booth, the toll booth can determine the identity of the radio frequency  
18 identification device, and thus of the owner of the device, and debit an account  
19 held by the owner for payment of toll or can receive a credit card number  
20 against which the toll can be charged. Similarly, remote payment is possible  
21 for a variety of other goods or services.  
22  
23

1 A communication system typically includes two transponders: a  
2 commander station or interrogator, and a responder station or transponder device  
3 which replies to the interrogator.

4 If the interrogator has prior knowledge of the identification number of  
5 a device which the interrogator is looking for, it can specify that a response  
6 is requested only from the device with that identification number. Sometimes,  
7 such information is not available. For example, there are occasions where the  
8 interrogator is attempting to determine which of multiple devices are within  
9 communication range.

10 When the interrogator sends a message to a transponder device requesting  
11 a reply, there is a possibility that multiple transponder devices will attempt to  
12 respond simultaneously, causing a collision, and thus causing an erroneous  
13 message to be received by the interrogator. For example, if the interrogator  
14 sends out a command requesting that all devices within a communications range  
15 identify themselves, and gets a large number of simultaneous replies, the  
16 interrogator may not be able to interpret any of these replies. Thus, arbitration  
17 schemes are employed to permit communications free of collisions.

18 In one arbitration scheme or system, described in commonly assigned  
19 U.S. Patent Nos. 5,627,544; 5,583,850; 5,500,650; and 5,365,551, all to  
20 Snodgrass et al. and all incorporated herein by reference, the interrogator sends  
21 a command causing each device of a potentially large number of responding  
22 devices to select a random number from a known range and use it as that  
23 device's arbitration number. By transmitting requests for identification to

1 various subsets of the full range of arbitration numbers, and checking for an  
2 error-free response, the interrogator determines the arbitration number of every  
3 responder station capable of communicating at the same time. Therefore, the  
4 interrogator is able to conduct subsequent uninterrupted communication with  
5 devices, one at a time, by addressing only one device.

6 Another arbitration scheme is referred to as the Aloha or slotted Aloha  
7 scheme. This scheme is discussed in various references relating to  
8 communications, such as Digital Communications: Fundamentals and  
9 Applications, Bernard Sklar, published January 1988 by Prentice Hall. In this  
10 type of scheme, a device will respond to an interrogator using one of many  
11 time domain slots selected randomly by the device. A problem with the Aloha  
12 scheme is that if there are many devices, or potentially many devices in the  
13 field (i.e. in communications range, capable of responding) then there must be  
14 many available slots or many collisions will occur. Having many available  
15 slots slows down replies. If the magnitude of the number of devices in a field  
16 is unknown, then many slots are needed. This results in the system slowing  
17 down significantly because the reply time equals the number of slots multiplied  
18 by the time period required for one reply.

19 An electronic identification system which can be used as a radio  
20 frequency identification device, arbitration schemes, and various applications for  
21 such devices are described in detail in commonly assigned U.S. Patent  
22 Application Serial Number 08/705,043, filed August 29, 1996, and incorporated  
23 herein by reference.

1 SUMMARY OF THE INVENTION

2 The invention provides a wireless identification device configured to  
3 provide a signal to identify the device in response to an interrogation signal.

4 One aspect of the invention provides a method of establishing wireless  
5 communications between an interrogator and individual ones of multiple wireless  
6 identification devices. The method comprises utilizing a tree search method to  
7 attempt to identify individual ones of the multiple wireless identification devices  
8 so as to be able to perform communications, without collision, between the  
9 interrogator and individual ones of the multiple wireless identification devices.

10 A search tree is defined for the tree search method. The tree has multiple  
11 nodes respectively representing subgroups of the multiple wireless identification  
12 devices. The interrogator transmits a command at a node, requesting that  
13 devices within the subgroup represented by the node respond. The interrogator  
14 determines if a collision occurs in response to the command and, if not, repeats  
15 the command at the same node.

16 Another aspect of the invention provides a communications system  
17 comprising an interrogator, and a plurality of wireless identification devices  
18 configured to communicate with the interrogator in a wireless fashion. The  
19 interrogator is configured to employ tree searching to attempt to identify  
20 individual ones of the multiple wireless identification devices, so as to be able  
21 to perform communications without collision, between the interrogator and  
22 individual ones of the multiple wireless identification devices. The interrogator  
23 is configured to follow a search tree, the tree having multiple nodes

1 respectively representing subgroups of the multiple wireless identification  
2 devices. The interrogator is configured to transmit a command at a node,  
3 requesting that devices within the subgroup represented by the node respond.  
4 The interrogator is further configured to determine if a collision occurs in  
5 response to the command and, if not, to repeat the command at the same node.

6 One aspect of the invention provides a radio frequency identification  
7 device comprising an integrated circuit including a receiver, a transmitter, and  
8 a microprocessor. In one embodiment, the integrated circuit is a monolithic  
9 single die single metal layer integrated circuit including the receiver, the  
10 transmitter, and the microprocessor. The device of this embodiment includes  
11 an active transponder, instead of a transponder which relies on magnetic  
12 coupling for power, and therefore has a much greater range.

#### 14 BRIEF DESCRIPTION OF THE DRAWINGS

15 Preferred embodiments of the invention are described below with  
16 reference to the following accompanying drawings.

17 Fig. 1 is a high level circuit schematic showing an interrogator and a  
18 radio frequency identification device embodying the invention.

19 Fig. 2 is a front view of a housing, in the form of a badge or card,  
20 supporting the circuit of Fig. 1 according to one embodiment the invention.

21 Fig. 3 is a front view of a housing supporting the circuit of Fig. 1  
22 according to another embodiment of the invention.  
23

Fig. 4 is a diagram illustrating a tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

Fig. 5. is a diagram illustrating a modified tree splitting sort method for establishing communication with a radio frequency identification device in a field of a plurality of such devices.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

This disclosure of the invention is submitted in furtherance of the constitutional purposes of the U.S. Patent Laws "to promote the progress of science and useful arts" (Article 1, Section 8).

Fig. 1 illustrates a wireless identification device 12 in accordance with one embodiment of the invention. In the illustrated embodiment, the wireless identification device is a radio frequency data communication device 12, and includes RFID circuitry 16. The device 12 further includes at least one antenna 14 connected to the circuitry 16 for wireless or radio frequency transmission and reception by the circuitry 16. In the illustrated embodiment, the RFID circuitry is defined by an integrated circuit as described in the above-incorporated patent application 08/705,043, filed August 29, 1996. Other embodiments are possible. A power source or supply 18 is connected to the integrated circuit 16 to supply power to the integrated circuit 16. In one embodiment, the power source 18 comprises a battery.



1 The device 12 transmits and receives radio frequency communications to  
2 and from an interrogator 26. An exemplary interrogator is described in  
3 commonly assigned U.S. Patent Application Serial No. 08/907,689, filed  
4 August 8, 1997 and incorporated herein by reference. Preferably, the  
5 interrogator 26 includes an antenna 28, as well as dedicated transmitting and  
6 receiving circuitry, similar to that implemented on the integrated circuit 16.

7 Generally, the interrogator 26 transmits an interrogation signal or  
8 command 27 via the antenna 28. The device 12 receives the incoming  
9 interrogation signal via its antenna 14. Upon receiving the signal 27, the  
10 device 12 responds by generating and transmitting a responsive signal or  
11 reply 29. The responsive signal 29 typically includes information that uniquely  
12 identifies, or labels the particular device 12 that is transmitting, so as to  
13 identify any object or person with which the device 12 is associated.

14 Although only one device 12 is shown in Fig. 1, typically there will be  
15 multiple devices 12 that correspond with the interrogator 26, and the particular  
16 devices 12 that are in communication with the interrogator 26 will typically  
17 change over time. In the illustrated embodiment in Fig. 1, there is no  
18 communication between multiple devices 12. Instead, the devices 12  
19 respectively communicate with the interrogator 26. Multiple devices 12 can be  
20 used in the same field of an interrogator 26 (i.e., within communications range  
21 of an interrogator 26).

22 The radio frequency data communication device 12 can be included in  
23 any appropriate housing or packaging. Various methods of manufacturing

1 housings are described in commonly assigned U.S. Patent Application Serial  
2 No. 08/800,037, filed February 13, 1997, and incorporated herein by reference.

3 Fig. 2 shows but one embodiment in the form of a card or badge 19  
4 including a housing 11 of plastic or other suitable material supporting the  
5 device 12 and the power supply 18. In one embodiment, the front face of the  
6 badge has visual identification features such as graphics, text, information found  
7 on identification or credit cards, etc.

8 Fig. 3 illustrates but one alternative housing supporting the device 12.  
9 More particularly, Fig. 3 shows a miniature housing 20 encasing the device 12  
10 and power supply 18 to define a tag which can be supported by an object  
11 (e.g., hung from an object, affixed to an object, etc.). Although two particular  
12 types of housings have been disclosed, other forms of housings are employed  
13 in alternative embodiments.

14 If the power supply 18 is a battery, the battery can take any suitable  
15 form. Preferably, the battery type will be selected depending on weight, size,  
16 and life requirements for a particular application. In one embodiment, the  
17 battery 18 is a thin profile button-type cell forming a small, thin energy cell  
18 more commonly utilized in watches and small electronic devices requiring a thin  
19 profile. A conventional button-type cell has a pair of electrodes, an anode  
20 formed by one face and a cathode formed by an opposite face. In an  
21 alternative embodiment, the power source 18 comprises a series connected pair  
22 of button type cells. In other alternative embodiments, other types of suitable  
23 power source are employed.

1       The circuitry 16 further includes a backscatter transmitter and is  
2 configured to provide a responsive signal to the interrogator 26 by radio  
3 frequency. More particularly, the circuitry 16 includes a transmitter, a  
4 receiver, and memory such as is described in U.S. Patent Application Serial  
5 Number 08/705,043.

6       Radio frequency identification has emerged as a viable and affordable  
7 alternative to tagging or labeling small to large quantities of items. The  
8 interrogator 26 communicates with the devices 12 via an electromagnetic link,  
9 such as via an RF link (e.g., at microwave frequencies, in one embodiment),  
10 so all transmissions by the interrogator 26 are heard simultaneously by all  
11 devices 12 within range.

12       If the interrogator 26 sends out a command requesting that all devices 12  
13 within range identify themselves, and gets a large number of simultaneous  
14 replies, the interrogator 26 may not be able to interpret any of these replies.  
15 Therefore, arbitration schemes are provided.

16       If the interrogator 26 has prior knowledge of the identification number  
17 of a device 12 which the interrogator 26 is looking for, it can specify that a  
18 response is requested only from the device 12 with that identification number.  
19 To target a command at a specific device 12, (i.e., to initiate point-on-point  
20 communication), the interrogator 26 must send a number identifying a specific  
21 device 12 along with the command. At start-up, or in a new or changing  
22 environment, these identification numbers are not known by the interrogator 26.  
23 Therefore, the interrogator 26 must identify all devices 12 in the field (within



1 them in a point-to-point fashion. Thus, arbitration in a RFID system is a  
2 transient rather than steady-state phenomenon. Further, the capability of a  
3 device 12 is limited by practical restrictions on size, power, and cost. The  
4 lifetime of a device 12 can often be measured in terms of number of  
5 transmissions before battery power is lost. Therefore, one of the most  
6 important measures of system performance in RFID arbitration is total time  
7 required to arbitrate a set of devices 12. Another measure is power consumed  
8 by the devices 12 during the process. This is in contrast to the measures of  
9 throughput and packet delay in other types of multiaccess systems.

10 Fig. 4 illustrates one arbitration scheme that can be employed for  
11 communication between the interrogator and devices 12. Generally, the  
12 interrogator 26 sends a command causing each device 12 of a potentially large  
13 number of responding devices 12 to select a random number from a known  
14 range and use it as that device's arbitration number. By transmitting requests  
15 for identification to various subsets of the full range of arbitration numbers,  
16 and checking for an error-free response, the interrogator 26 determines the  
17 arbitration number of every responder station capable of communicating at the  
18 same time. Therefore, the interrogator 26 is able to conduct subsequent  
19 uninterrupted communication with devices 12, one at a time, by addressing only  
20 one device 12.

21 Three variables are used: an arbitration value (AVALUE), an arbitration  
22 mask (AMASK), and a random value ID (RV). The interrogator sends an  
23 Identify command (IdentifyCmnd) causing each device of a potentially large

number of responding devices to select a random number from a known range and use it as that device's arbitration number. The interrogator sends an arbitration value (AVALUE) and an arbitration mask (AMASK) to a set of devices 12. The receiving devices 12 evaluate the following equation:  $(AMASK \& AVALUE) == (AMASK \& RV)$  wherein "&" is a bitwise AND function, and wherein "==" is an equality function. If the equation evaluates to "1" (TRUE), then the device 12 will reply. If the equation evaluates to "0" (FALSE), then the device 12 will not reply. By performing this in a structured manner, with the number of bits in the arbitration mask being increased by one each time, eventually a device 12 will respond with no collisions. Thus, a binary search tree methodology is employed.

An example using actual numbers will now be provided using only four bits, for simplicity, reference being made to Fig. 4. In one embodiment, sixteen bits are used for AVALUE and AMASK. Other numbers of bits can also be employed depending, for example, on the number of devices 12 expected to be encountered in a particular application, on desired cost points, etc.

Assume, for this example, that there are two devices 12 in the field, one with a random value (RV) of 1100 (binary), and another with a random value (RV) of 1010 (binary). The interrogator is trying to establish communications without collisions being caused by the two devices 12 attempting to communicate at the same time.

1 The interrogator sets AVALUE to 0000 (or "don't care" for all bits, as  
2 indicated by the character "X" in Fig. 4) and AMASK to 0000. The  
3 interrogator transmits a command to all devices 12 requesting that they identify  
4 themselves. Each of the devices 12 evaluate  
5  $(AMASK \& AVALUE) == (AMASK \& RV)$  using the random value RV that  
6 the respective devices 12 selected. If the equation evaluates to "1" (TRUE),  
7 then the device 12 will reply. If the equation evaluates to "0" (FALSE), then  
8 the device 12 will not reply. In the first level of the illustrated tree, AMASK  
9 is 0000 and anything bitwise ANDed with all zeros results in all zeros, so  
10 both the devices 12 in the field respond, and there is a collision.

11 Next, the interrogator sets AMASK to 0001 and AVALUE to 0000 and  
12 transmits an Identify command. Both devices 12 in the field have a zero for  
13 their least significant bit, and  $(AMASK \& AVALUE) == (AMASK \& RV)$  will  
14 be true for both devices 12. For the device 12 with a random value of 1100,  
15 the left side of the equation is evaluated as follows  $(0001 \& 0000) = 0000$ .  
16 The right side is evaluated as  $(0001 \& 1100) = 0000$ . The left side equals the  
17 right side, so the equation is true for the device 12 with the random value  
18 of 1100. For the device 12 with a random value of 1010, the left side of the  
19 equation is evaluated as  $(0001 \& 0000) = 0000$ . The right side is evaluated  
20 as  $(0001 \& 1010) = 0000$ . The left side equals the right side, so the equation  
21 is true for the device 12 with the random value of 1010. Because the  
22 equation is true for both devices 12 in the field, both devices 12 in the field  
23 respond, and there is another collision.

00440-0440

1            Recursively, the interrogator next sets AMASK to 0011 with AVALUE  
2 still at 0000 and transmits an Identify command.  
3  $(AMASK \& AVALUE) = (AMASK \& RV)$  is evaluated for both devices 12.  
4 For the device 12 with a random value of 1100, the left side of the equation  
5 is evaluated as follows  $(0011 \& 0000) = 0000$ . The right side is evaluated  
6 as  $(0011 \& 1100) = 0000$ . The left side equals the right side, so the equation  
7 is true for the device 12 with the random value of 1100, so this device 12  
8 responds. For the device 12 with a random value of 1010, the left side of  
9 the equation is evaluated as  $(0011 \& 0000) = 0000$ . The right side is evaluated  
10 as  $(0011 \& 1010) = 0010$ . The left side does not equal the right side, so the  
11 equation is false for the device 12 with the random value of 1010, and this  
12 device 12 does not respond. Therefore, there is no collision, and the  
13 interrogator can determine the identity (e.g., an identification number) for the  
14 device 12 that does respond.

15            De-recursion takes place, and the devices 12 to the right for the same  
16 AMASK level are accessed when AVALUE is set at 0010, and AMASK is set  
17 to 0011.

18            The device 12 with the random value of 1010 receives a command and  
19 evaluates the equation  $(AMASK \& AVALUE) = (AMASK \& RV)$ . The left  
20 side of the equation is evaluated as  $(0011 \& 0010) = 0010$ . The right side of  
21 the equation is evaluated as  $(0011 \& 1010) = 0010$ . The right side equals the  
22 left side, so the equation is true for the device 12 with the random value  
23 of 1010. Because there are no other devices 12 in the subtree, a good reply



1 is returned by the device 12 with the random value of 1010. There is no  
2 collision, and the interrogator 26 can determine the identity (e.g., an  
3 identification number) for the device 12 that does respond.

4 By recursion, what is meant is that a function makes a call to itself.  
5 In other words, the function calls itself within the body of the function. After  
6 the called function returns, de-recursion takes place and execution continues at  
7 the place just after the function call; i.e. at the beginning of the statement after  
8 the function call.

9 For instance, consider a function that has four statements  
10 (numbered 1,2,3,4) in it, and the second statement is a recursive call. Assume  
11 that the fourth statement is a return statement. The first time through the loop  
12 (iteration 1) the function executes the statement 2 and (because it is a recursive  
13 call) calls itself causing iteration 2 to occur. When iteration 2 gets to  
14 statement 2, it calls itself making iteration 3. During execution in iteration 3  
15 of statement 1, assume that the function does a return. The information that  
16 was saved on the stack from iteration 2 is loaded and the function resumes  
17 execution at statement 3 (in iteration 2), followed by the execution of  
18 statement 4 which is also a return statement. Since there are no more  
19 statements in the function, the function de-recurses to iteration 1. Iteration 1,  
20 had previously recursively called itself in statement 2. Therefore, it now  
21 executes statement 3 (in iteration 1). Following that it executes a return at  
22 statement 4. Recursion is known in the art.  
23

17

1 Consider the following code which can be used to implement operation  
2 of the method shown in Fig. 4 and described above.

3 Arbitrate(AMASK, AVALUE)  
4 {  
5 collision=IdentifyCmnd(AMASK, AVALUE)  
6 if (collision) then  
7 {  
8 /\* recursive call for left side \*/  
9 Arbitrate((AMASK<<1)+1, AVALUE)  
10 /\* recursive call for right side \*/  
11 Arbitrate((AMASK<<1)+1, AVALUE+(AMASK+1))  
12 } /\* endif \*/  
13 } /\* return \*/  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23

10 The symbol "<<" represents a bitwise left shift. "<<1" means shift  
11 left by one place. Thus, 0001<<1 would be 0010. Note, however, that  
12 AMASK is originally called with a value of zero, and 0000<<1 is still 0000.  
13 Therefore, for the first recursive call, AMASK = (AMASK<<1)+1. So for  
14 the first recursive call, the value of AMASK is 0000+0001=0001. For the  
15 second call, AMASK=(0001<<1)+1=0010+1=0011. For the third recursive  
16 call, AMASK=(0011<<1)+1=0110+1=0111.

17 The routine generates values for AMASK and AVALUE to be used by  
18 the interrogator in an Identify command "IdentifyCmnd." Note that the routine  
19 calls itself if there is a collision. De-recursion occurs when there is no  
20 collision. AVALUE and AMASK would have values such as the following  
21 assuming collisions take place all the way down to the bottom of the tree.  
22  
23

AVALUE	AMASK
0000	0000
0000	0001
0000	0011
0000	0111
0000	1111*
1000	1111*
0100	0111
0100	1111*
1100	1111*

This sequence of AMASK, AVALUE binary numbers assumes that there are collisions all the way down to the bottom of the tree, at which point the Identify command sent by the interrogator is finally successful so that no collision occurs. Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol "\*". Note that if the Identify command was successful at, for example, the third line in the table then the interrogator would stop going down that branch of the tree and start down another, so the sequence would be as shown in the following table.

AVALUE	AMASK
0000	0000
0000	0001
0000	0011*
0010	0011
...	...

This method is referred to as a splitting method. It works by splitting groups of colliding devices 12 into subsets that are resolved in turn. The splitting method can also be viewed as a type of tree search. Each split moves the method one level deeper in the tree. Either depth-first or breadth-first traversals of the tree can be employed. Depth first traversals are performed by using recursion, as is employed in the code listed above. Breadth-first traversals are accomplished by using a queue instead of recursion.

Either depth-first or breadth-first traversals of the tree can be employed. Depth first traversals are performed by using recursion, as is employed in the code listed above. Breadth-first traversals are accomplished by using a queue instead of recursion. The following is an example of code for performing a breadth-first traversal.

```

1 Arbitrate(AMASK, AVALUE)
2 {
3   enqueue(0,0)
4   while (queue != empty)
5     (AMASK,AVALUE) = dequeue()
6     collision=IdentifyCmnd(AMASK, AVALUE)
7     if (collision) then
8       {
9         TEMP = AMASK+1
10        NEW_AMASK = (AMASK < < 1)+1
11        enqueue(NEW_AMASK, AVALUE)
12        enqueue(NEW_AMASK, AVALUE+TEMP)
13      } /* endif */
14   endwhile
15
16   }/* return */

```

The symbol "!=" means not equal to. AVALUE and AMASK would have values such as those indicated in the following table for such code.

AVALUE	AMASK
0000	0000
0000	0001
0001	0001
0000	0011
0010	0011
0001	0011
0011	0011
0000	0111
0100	0111
...	...

1 Rows in the table for which the interrogator is successful in receiving  
2 a reply without collision are marked with the symbol "\*".

3 Fig. 5 illustrates an embodiment wherein the interrogator 26 retries on  
4 the same node that yielded a good reply. The search tree has a plurality of  
5 nodes 51, 52, 53, 54 etc. at respective levels 32, 34, 36, 38, or 40. The  
6 size of subgroups of random values decrease in size by half with each node  
7 descended.

8 The interrogator performs a tree search, either depth-first or breadth-first  
9 in a manner such as that described in connection with Fig. 4, except that if  
10 the interrogator determines that no collision occurred in response to an Identify  
11 command, the interrogator repeats the command at the same node. This takes  
12 advantage of an inherent capability of the devices, particularly if the devices  
13 use backscatter communication, called self-arbitration. Arbitration times can be  
14 reduced, and battery life for the devices can be increased.

15 When a single reply is read by the interrogator, for example, in node  
16 52, the method described in connection with Fig. 4 would involve proceeding  
17 to node 53 and then sending another Identify command. Because a device 12  
18 in a field of devices 12 can override weaker devices, this embodiment is  
19 modified such that the interrogator retries on the same node 52 after silencing  
20 the device 12 that gave the good reply. Thus, after receiving a good reply  
21 from node 52, the interrogator remains on node 52 and reissues the Identify  
22 command after silencing the device that first responded on node 52. Repeating  
23

1 the Identify command on the same node often yields other good replies, thus  
2 taking advantage of the devices natural ability to self-arbitrate.

3 AVALUE and AMASK would have values such as the following for a  
4 depth-first traversal in a situation similar to the one described above in  
5 connection with Fig. 4.  
6  
7  
8  
9  
10  
11  
12  
13  
14  
15  
16  
17  
18  
19  
20  
21  
22  
23

CB

70240

AVALUE	AMASK
0000	0000
0000	0001
0000	0011
0000	0111
0000	1111*
0000	1111*
1000	1111*
1000	1111*
0100	0111
0100	1111*
0100	1111*
1100	1111*
1100	1111*

Rows in the table for which the interrogator is successful in receiving a reply without collision are marked with the symbol "\*\*".

In operation, the interrogator transmits a command at a node, requesting that devices within the subgroup represented by the node respond. The interrogator determines if a collision occurs in response to the command and, if not, repeats the command at the same node.

In one alternative embodiment, the upper bound of the number of devices 12 in the field (the maximum possible number of devices that could communicate with the interrogator) is determined, and the tree search method is started at a level 32, 34, 36, 38, or 40 in the tree depending on the determined upper bound. The level of the search tree on which to start the



tree search is selected based on the determined maximum possible number of wireless identification devices that could communicate with the interrogator. The tree search is started at a level determined by taking the base two logarithm of the determined maximum possible number. More particularly, the tree search is started at a level determined by taking the base two logarithm of the power of two nearest the determined maximum possible number of devices 12. The level of the tree containing all subgroups of random values is considered level zero, and lower levels are numbered 1, 2, 3, 4, etc. consecutively.

Methods involving determining the upper bound on a set of devices and starting at a level in the tree depending on the determined upper bound are described in a commonly assigned patent application (attorney docket MI40-118) naming Clifton W. Wood, Jr. as an inventor, titled "Method of Addressing Messages and Communications System," filed concurrently herewith, and incorporated herein by reference.

In one alternative embodiment, a method involving starting at a level in the tree depending on a determined upper bound (such as the method described in the commonly assigned patent application mentioned above) is combined with a method comprising re-trying on the same node that gave a good reply, such as the method shown and described in connection with Fig. 5.

Another arbitration method that can be employed is referred to as the "Aloha" method. In the Aloha method, every time a device 12 is involved in a collision, it waits a random period of time before retransmitting. This

method can be improved by dividing time into equally sized slots and forcing transmissions to be aligned with one of these slots. This is referred to as "slotted Aloha." In operation, the interrogator asks all devices 12 in the field to transmit their identification numbers in the next time slot. If the response is garbled, the interrogator informs the devices 12 that a collision has occurred, and the slotted Aloha scheme is put into action. This means that each device 12 in the field responds within an arbitrary slot determined by a randomly selected value. In other words, in each successive time slot, the devices 12 decide to transmit their identification number with a certain probability.

The Aloha method is based on a system operated by the University of Hawaii. In 1971, the University of Hawaii began operation of a system named Aloha. A communication satellite was used to interconnect several university computers by use of a random access protocol. The system operates as follows. Users or devices transmit at any time they desire. After transmitting, a user listens for an acknowledgment from the receiver or interrogator. Transmissions from different users will sometimes overlap in time (collide), causing reception errors in the data in each of the contending messages. The errors are detected by the receiver, and the receiver sends a negative acknowledgment to the users. When a negative acknowledgment is received, the messages are retransmitted by the colliding users after a random delay. If the colliding users attempted to retransmit without the random delay, they would collide again. If the user does not receive either an acknowledgment

1 or a negative acknowledgment within a certain amount of time, the user "times  
2 out" and retransmits the message.

3 There is a scheme known as slotted Aloha which improves the Aloha  
4 scheme by requiring a small amount of coordination among stations. In the  
5 slotted Aloha scheme, a sequence of coordination pulses is broadcast to all  
6 stations (devices). As is the case with the pure Aloha scheme, packet lengths  
7 are constant. Messages are required to be sent in a slot time between  
8 synchronization pulses, and can be started only at the beginning of a time slot.  
9 This reduces the rate of collisions because only messages transmitted in the  
10 same slot can interfere with one another. The retransmission mode of the pure  
11 Aloha scheme is modified for slotted Aloha such that if a negative  
12 acknowledgment occurs, the device retransmits after a random delay of an  
13 integer number of slot times.

14 Aloha methods are described in a commonly assigned patent application  
15 (attorney docket MI40-089) naming Clifton W. Wood, Jr. as an inventor, titled  
16 "Method of Addressing Messages and Communications System," filed  
17 concurrently herewith, and incorporated herein by reference.

18 In one alternative embodiment, an Aloha method (such as the method  
19 described in the commonly assigned patent application mentioned above) is  
20 combined with a method involving re-trying on the same node that gave a good  
21 reply, such as the method shown and described in connection with Fig. 5.

22 In another embodiment, levels of the search tree are skipped. Skipping  
23 levels in the tree, after a collision caused by multiple devices 12 responding,

reduces the number of subsequent collisions without adding significantly to the number of no replies. In real-time systems, it is desirable to have quick arbitration sessions on a set of devices 12 whose unique identification numbers are unknown. Level skipping reduces the number of collisions, both reducing arbitration time and conserving battery life on a set of devices 12. In one embodiment, every other level is skipped. In alternative embodiments, more than one level is skipped each time.

The trade off that must be considered in determining how many (if any) levels to skip with each descent down the tree is as follows. Skipping levels reduces the number of collisions, thus saving battery power in the devices 12. Skipping deeper (skipping more than one level) further reduces the number of collisions. The more levels that are skipped, the greater the reduction in collisions. However, skipping levels results in longer search times because the number of queries (Identify commands) increases. The more levels that are skipped, the longer the search times. Skipping just one level has an almost negligible effect on search time, but drastically reduces the number of collisions. If more than one level is skipped, search time increases substantially. Skipping every other level drastically reduces the number of collisions and saves battery power without significantly increasing the number of queries.

Level skipping methods are described in a commonly assigned patent application (attorney docket MI40-117) naming Clifton W. Wood, Jr. and Don Hush as inventors, titled "Method of Addressing Messages, Method of

1 Establishing Wireless Communications, and Communications System," filed  
2 concurrently herewith, and incorporated herein by reference.

3 In one alternative embodiment, a level skipping method is combined with  
4 a method involving re-trying on the same node that gave a good reply, such  
5 as the method shown and described in connection with Fig. 5.

6 In yet another alternative embodiment, any two or more of the methods  
7 described in the commonly assigned, concurrently filed, applications mentioned  
8 above are combined.

9 In compliance with the statute, the invention has been described in  
10 language more or less specific as to structural and methodical features. It is  
11 to be understood, however, that the invention is not limited to the specific  
12 features shown and described, since the means herein disclosed comprise  
13 preferred forms of putting the invention into effect. The invention is,  
14 therefore, claimed in any of its forms or modifications within the proper scope  
15 of the appended claims appropriately interpreted in accordance with the doctrine  
16 of equivalents.